Distant Air Traffic Control for Regional Airports

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Abstract: This paper reports on field research conducted within the project VICTOR[1] – Virtual Control Tower Research Studies – supported by the German air navigation service provider DFS-Deutsche Flugsicherung and concerned with the development of a distant tower facility for small or regional airports. In an user-centered approach, the provision of adequate information formerly acquired via looking out of the tower window is addressed. Subsequent research and development iterations are conducted engaging controllers at local airports throughout the process. The paper reports on results of a work analysis performed at three regional German airports and their implications for the design of a distant control tower.

Keywords: air traffic control, remote tower, regional airport, task analysis

1. INTRODUCTION

Air transport is crucial for a country's international connection, export economy, and tourism and it is a growing sector worldwide. The safe, efficient, and fluent processing of the occuring air traffic is the main goal and task of air traffic control and management (ATC/ATM). For nearly one century, aerodrome air traffic control has been based on visual surveillance of the airport premises and the adjacent airspace out of the control-tower window. The scalability of common control towers regarding the provision of capacity needed is limited on the one hand by expanding airports and therewith visual space to be covered and on the other hand by changing weather conditions and the respective visibility reduction (cp., Schulz-Rueckert, 2009).

1.1 The VICTOR Project

The increase of air traffic has triggered international efforts to build a controller working place independent from visibility conditions and location in order to meet the expected demands on capacity as well as to ensure overall safety in ATC. Different theoretical assumptions as well as a variety of new developments in avionics and ground-sensor technology have led to multiple approaches towards remotely controlled aerodromes in various projects and initiatives such as RAiCe (Remote Airport Traffic Control Center) of German Aerospace Center (DLR), ROT (Remotely Operated Tower) of Saab and the LFV Group (Swedish Airports and Air Navigation Services) and the realisation of the Virtual Contingency Facility at Heathrow Airport. Often, ATC at large and international airports is addressed. Within the German Aviation Research Program iPort the DFS-supported project VICTOR (Virtual Control Tower Research Studies) is concerned with the development of a distant tower facility for small or regional airports. These airports are characterised by a heterogeneity of equipment and infrastructure as well as a large proportion of hard to schedule VFR-traffic. In an user-centered approach, the visual information intake and communication processes are analysed. Subsequently, work place concepts are developed providing adequate information which has been formerly acquired via looking out of the tower window. The research and development iterations are conducted engaging controllers at local airports throughout the process. Basis for the evaluation is a detailed analysis of the controller's activities which has been conducted on three German regional airports (cp., Wittbrodt, Gross, & Thüring, accepted).

1.2 Related Research

The controller working place is one with many safety restrictions and very critical regarding data collection. Therefore, few field studies concerning the gaze behaviour of tower controllers can be found. An extensive study was conducted by EUROCONTROL in 2005. Pinska and colleagues observed controllers via video analysis and analysed their activity allocation at Warsaw Frederic Chopin Airport (Pinska & Bourgois, 2007). They found, amongst others, that the view outside the tower window was the major activity as to frequency as well as duration of visual behaviour. Pinska and Bourgois report scanning activities of

[1] The project is embedded within the German Aviation Research Programme iPort – innovate Airport funded by the German Federal Ministry of Economics and Technology.

runway and apron of 37% and 40.5% in frequency for tower and ground controller, respectively (p. 12f.). Runway scanning took the tower controller 7.1s, apron scanning 6.2s, and, similarly, the ground controller was occupied 6.8s with runway scanning and 5.5s with apron scanning in average.

2. DESIGNING A NEW CONTROLLER WORK ENVIRONMENT

When creating a new work environment, a user-centered approach ensures that the users' needs are considered and integrated in the application design which in turn improves overall acceptance, reduces the risk of major design errors, and thereby pays off in financial terms in the long run. The standard development process model (ISO 13407) provides guidance on design activities that take place throughout the life cycle of the development process. It describes an iterative development cycle where product requirements specifications correctly account for user and organisational requirements. The context in which the product in question is to be used is specified and design solutions are then produced which can be evaluated by representative users.

The overall research plan therefore follows an iterative development process (cp. Fig. 1).

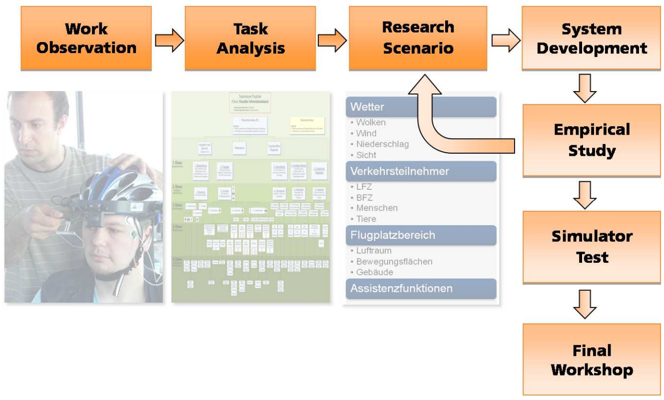

Fig. 1. Research process in VICTOR

To meet user requirements within VICTOR a work analysis was conducted as initial development step. The main goals of the work analysis were the investigation of the controllers' visual information intake and working processes as well as to generally gain an overall, thorough understanding of the tasks to be fulfilled by a tower controller at a regional airport.

In order to cover a representative range of situations and working conditions we decided for variegating the traffic volume and mixture, i.e., the proportion of VFR (visual flight rules) and IFR (instrumental flight rules) traffic. Other variables such as weather and visibility conditions were to be held constant as far as possible. The study was conducted at the regional airports Leipzig-Altenburg (AOC), Niederrhein Weeze (NRN), and Dortmund (DTM). The three airports differ in traffic density (low: AOC, medium: NRN, high: DTM), traffic mixture, and equipment. An analysis of the traffic data and flight plans led to the decision for an observation in early summer with expected good visibility and constant weather conditions.

3. METHOD

3.1 Participants

Eight traffic controllers with an average age of 32 years (range 25-46yrs) took part in the study (1 female). The participants had a minimum expertise of 2 years of ATC (mean=7yrs). Four controllers wore spectacles.

3.2 Setting

The layout of the three airports is very similar. Each airport holds one runway approved usable for both directions and provides different navigation assistance systems for pilots. Each runway features an instrument landing system (ILS) enabling approaches at least in one operational direction under conditions of poor visibility. Four taxiways connect runway and apron. ATC services are provided by TTC The Tower Company. The control towers are each located in the southern part of the airport central towards the runway. Besides the operational areas, a control airspace up to 2,500ft MSL (Mean Sea Level) is monitored in Altenburg und Dortmund and up to 3,000ft MSL in Niederrhein, respectively. The control zone is defined as class D airspace.

Despite the similar layout, the work places differ considerably regarding equipment and arrangement of technical aids. In Altenburg a radio direction finder is used to assist target identification. At Niederrhein airport controllers are supported in traffic forecast by a semi-digital flight strip system and a digital flight book.

The ATC-personnel work assignment follows airport-specific arrangements at each of the three locations. Only in Dortmund a classical work distribution was observable, i.e., ATC services were split between a tower controller responsible for take-offs and landings and a ground controller responsible for the movements on taxiways and holding areas. In Altenburg only one controller held both positions for handling the air and ground traffic. In Niederrhein the work was allocated between two controllers, whereas one was involved in coordination and the other controller performed the tasks relevant for ACT.

3.3 Measures and Procedure

In order to capture the controllers‘ visual information intake a head-mounted eye-tracker was used (iView X™ HED by SMI). Two cameras were directed towards the tower interior and the apron. A microphone collected the audio data perceivable within the tower cab. Audio data of communication aids such as voice radio was provided by TTC. The controllers received a workload questionnaire (NASA-TLX, Hart & Staveland, 1988). A standardised interview regarding their current shift, the working equipment, and the importance of the view outside the tower window for their work was conducted after each observation session. An observation session took 60-90min for each controller and was conducted during the regular work shift. Pictures were taken for a detailed working place description.

After technical set-up and oral instructions the controllers were equipped with the eye-tracker and the system was calibrated. During the observation the reseachers left the tower cab, only the technician checked the measurement equipment periodically in order to ensure high gaze-data quality. After the session the controller filled in the questionnaire and was interviewed.

4. RESULTS

Despite the analysis of traffic volume of the previous year, a high traffic fluctuation due to an unpredictable weather situation was encountered. However, at least one typical day per trial was observed.

In Altenburg there were no unscheduled events whereas in Niederrhein there was a missed approach, an unplanned push-back and a fox at the ground. In Dortmund the ILS was calibrated during the observation and there was a helicopter flight crossing the control zone.

4.1 Workload

Workload was assessed via NASA-TLX and via a simple three-point workload scale. The controllers predominantly assessed their workload as little demanding (6 out of 9). Table 1 shows the aggregated NASA-TLX scores for all controllers. We used no weighting procedure for the six dimensions (cp., Byers, Bittner, & Hill, 1989).

Table 1. NASA-TLX-scores: mean and standard deviation (SD), N=8

Dimension	Mean	*SD*
Mental demand	30.5	*14.6*
Physical demand	9.6	*3.7*
Temporal demand	23.4	*17.5*
Performance	26.3	*15.5*
Frustration level	15.8	*7.1*
Effort	27.1	*17.5*

The controllers rated their mental demand and their effort in accomplishing their tasks highest with scores of 30.5 and 27.1, respectively. Performance and temporal demand were assessed with medium scores whereas frustration level and especially physical demand were judged as low. The data's predominant purpose was to give an impression of the controllers' workload structure during regular shifts at regional airports in order to compare the results with workload assessments in future research settings.

4.2 Gaze Analysis

The gaze-data was prepared for analysis by integrating the different camera perspectives into one overall video stream playable framewise. For each airport tower, twelve comparable areas-of-interest (AOI) were defined. They represented the sources of information available for the controller to fulfill his tasks. The gaze-analysis was performed manually by trained raters. The videos were analysed regarding the

- usage frequency – how often an AOI is gazed at,
- usage duration – the percentage of time gazed at the different sources of information in reference to the overall observation time.

In Altenburg a single controller was observed repeatedly in three sessions distributed over two subsequent days. The data of the three observations was aggregated. The results are reported in Table 2.

Table 2. Overall usage frequencies [%]

Information Category	AOC n=1, 3 trials	NRN n=1	DTM n=3
out of window	53.8	28.0	26.2
day flight plan	N/A	13.0	N/A
weather monitor	10.7	3.0	3.6
radar/table maps	1.8	19.2	30.9
flight strips	12.9	12.7	20.5
lighting control panel	0.8	2.6	1.6
radiogoniometer	3.8	2.9	3.6
other	14.1	15.2	12.9
error/not codable	1.9	3.3	0.6

In Altenburg the direct view out of the window is the source of information used most frequently with nearly 54%, followed by flight strips and weather monitor. A relatively large proportion of gazes was also categorised *other*. Radiogoniometer, table maps, and lighting control panel seem to play a marginal role with a total of 6.4%.

Gazing out of the tower window was much less observed in Niederrhein (28%), followed by radar/table maps, flight plan, and flight strips. Non-categorised objects were gazed at with a proportion of 15.2%.

In Dortmund, radar/table maps are gazed at more frequently than the events and objects directly observable outside the tower window with 30.9% vs 26.2%. The flight strips followed by non-categorised objects composed other major gaze locations.

Table 3. Gaze duration [s]: mean and standard deviation

Information Category	AOC n=1, 3 trials		NRN n=1		DTM n=3	
out of window	4.9	*1.4*	4.7	*0.9*	4.0	*0.9*
day flight plan	N/A		5.2	*0.1*	N/A	
weather monitor	2.9	*0.5*	2.4	*0.5*	1.9	*0.5*
radar/table maps	3.2	*0.7*	2.3	*0.6*	4.1	*0.7*
flight strips	4.5	*0.3*	4.4	*1.3*	2.6	*0.6*
lighting control panel	2.4	*1.0*	2.3	*0.3*	3.8	*2.0*
radiogoniometer	2.0	*0.8*	3.2	*1.9*	1.7	*0.2*
other	5.0	*1.2*	5.9	*2.3*	3.3	*1.0*
error/not codable	3.1	*1.2*	4.1	*1.6*	3.2	*0.9*

The gaze duration for the information categories is listed in Table 3. In Altenburg and Niederrhein the average intake of information from the direct view out of the window took almost 5s, followed by gaze durations on flight strips (4.5s and 4.4s). Also the non-defined objects category items received the longer gazes with 5s and 5.9s. Overall, in Dortmund shorter gazes were observed with the categories radar and gaze out of the window taking 4s in average. The lighting control panel was gazed at for a longer period in average (3.8s). Due to the ILS-measurement the panel was in overall use for a substantial period of time.

Summarising the eye-tracking results, some similarities and dissimilarities between the observed airports become evident. The flight-strip usage at the two towers in Niederrhein and Altenburg is quite similar, whereas their usage in Dortmund is almost twice as high. This might be due to the considerably larger traffic volume observed at Dortmund with an average of more than 18 aircraft movements during a trial. In Altenburg and Niederrhein only around 7 aircraft movements were counted. A higher amount of aircraft to be processed naturally increases flight strip usage. The traffic density might have also led to a longer gaze duration at non-classified objects in Altenburg and Niederrhein compared to Dortmund.

The weather monitor in Altenburg was used considerably more frequently than at the remaining towers. One reason could be a frequent time check since the monitor also provides the time. On the other hand the controller might have to pass more detailed weather information to the pilots due to the absence of an Automatic Terminal Information Service (ATIS) usually used for providing weather information automatically.

Depending on the airport investigated, the view out of the window was used most frequent (Altenburg) or second most frequently (Niederrhein and Dortmund) which corresponded with the relatively long gaze durations for this category. Only in Dortmund, radar and table maps were gazed at more frequently than objects out of the tower window. Not surprisingly, the proportion of out-of-window gazes was highest at Altenburg airport because the tower does not have a radar monitor which in turn was used quite frequently in Niederrhein and Dortmund. At Niederrhein airport a flight plan is provided which led to similar proportions of assistance system usage for traffic prediction (radar *and* flight plan) as observed at Dortmund airport. Overall, the high proportion of gazes out of the tower window confirms the importance of this source of information and is in line with the findings reported in Pinska & Bourgois (2007).

4.3 Interview Results

The verbal information given during the interview was categorised and as far as possible aggregated. As for the gaze-data, only a fraction of the results is reported here due to the abundance of information gathered.

A major question was the subjective assessement of the importance of gathering visual information from outside for fulfilling the controllers' tasks. Table 4 provides an overview on how much the view outside the tower window preponderates when fulfilling ATC tasks and which information is gathered.

Table 4. Importance of outside view and information gathered

	importance	information gathered (for)
AOC	95%	It is the main task. Position of aircraft and vehicles Separation interval Mental model
NRN	60-80%	It represents active work. Which objects moves on the facility/operational space? Are vehicles removed? Is the facility space vacated? Runway clear of people and vehicles? Landing gear of departing and approaching aircraft OK? Do people comply with the controllers' instructions?
DTM	50-70% depending on weather situation	Runway clear? Flock of birds, deer, rabits? Facility/operational space Weather observation Used also when IFR-traffic is approaching (status of landing gear) Planning is done using radar

The view outside the tower window is assessed with a weight of 50%-95% for performing ATC-tasks. The information gathered includes the controlling of aircraft status, vehicles, people, airport facilities, and weather. The importance and the actual usage of this source of information differ somewhat, possibly because of the different perspectives towards this aspect. Therefore, it seems possible that the perceived importance of the view out of the tower window exceeds its actual usage proportion.

In case areas of the airfield are not fully observable, e.g., at Altenburg, the controllers use binoculars and communicate more via radio for instance with pilots to gather detailed information. In Dortmund video cameras allow inspection at poorly visible locations.

5. CONCLUSIONS

Our primary goal to gain a thorough impression of the tasks to be fulfilled by controllers at regional airports has been reached. The findings regarding usage of information sources are in line with results of a tower observations at an international airport (cp. Pinska & Bourgois, 2007).

Besides the traffic volume, the gaze behaviour seems to depend on the technical inventory present in the tower. Reliable information and assistance systems are used frequently if available at the working place. If equipment is scarce, on the contrary, the view out of the tower window is the major source of information. The analysis of the interviews suggests as well that the view outside is of major importance depending on the weather condition, and again, the availability of technical equipment. The actual usage of assistance systems, especially in low visibility conditions, provides a vantage point for the reduction of the primacy of visual information intake based on the direct vision out of the tower window. A development towards sensor-based data and instrumental information as major source for ATC decision making is crucial for an independency from visibility constraints and tower location. The results of our study encourage a further promotion of this development.

An inquiry regarding additional assistance not reported here also showed a high dependence of controllers' requirements and suggestions on the heterogeneity of the systems in use. This heterogeneity will be a challenge when developing a concept for a new controller working place which is to meet requirements of users from different towers with the respective heterogeneity in equipment experience. Standardised equipment and a corresponding concept of operations may be key factors for a successful implementation of information and assistance systems at future remote towers.

6. OUTLOOK

The tower observation subsequently serves as a base for different design steps within the user-centered approach. Initially, a task analysis was conducted which was on the one hand based on the operational instruction manuals for ATC. On the other hand, the observations at Altenburg and Niederrhein provided valuable input regarding a working situation with combined functions and tasks. These aspects of work allocation were considered in a generic task description as well.

In parallel, a requirements catalogue for the new controller working place was developed with a weighting procedure regarding the importance of pieces of visual information for ATC tasks such as the location of an aircraft or its overall status. Subsequently, an interface concept is designed which is to meet these functional requirements as well as to comply with usability standards. Thereby, on the one hand the depiction of direct window-view information and instrument-based data have to be mapped in an appropriate way. On the other hand a transfer of a whole new concept regarding data reliability, data integration, and information intake has to be realised. Following the user-centered design process, the concept will be tested with expert users, i.e. controllers of regional airports. Research scenarios for prototype testing will thereby be based on the observed traffic situations at Leipzig-Altenburg, Niederrhein Weeze, and Dortmund.

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